

CLAIMS

What is claimed is:

1. An apparatus, comprising:

first and second multi-mode interference (MMI) coupling devices disposed in a semiconductor substrate, each of the first and second MMI coupling devices including first and second inputs and first and second outputs;

a first optical coupler having a first optical path length, the first output of the first MMI coupling device optically coupled to the first input of the second MMI coupling device through the first optical coupler; and

a second optical coupler having a second optical path length, the second output of the first MMI coupling device optically coupled to the second input of the second MMI coupling device through the second optical coupler, wherein the first optical path length is different than the second optical path length.

2. The apparatus of claim 1 wherein the first input of the first MMI coupling device is optically coupled to receive an optical beam having a plurality of channels, each one of the plurality of channels having a corresponding wavelength, wherein the first output of the second MMI coupling device is optically coupled to output a first one of the plurality of channels of the optical beam, wherein the second output of the second MMI coupling device is optically coupled to output a second one of the plurality of channels of the optical beam.

3. The apparatus of claim 1 wherein the first input of the first MMI coupling device is optically coupled to receive an optical beam having a plurality of channels, each one of the

3 plurality of channels having a corresponding wavelength, wherein the first output of the
 4 second MMI coupling device is optically coupled to output a first subset of the plurality of
 5 channels of the optical beam, wherein the second output of the second MMI coupling device
 6 is optically coupled to output a second subset of the plurality of channels of the optical beam.

1 4. The apparatus of claim 1 wherein the first output of the second MMI coupling
 2 device is optically coupled to receive a first optical beam having a first wavelength, wherein
 3 the second output of the second MMI coupling device is optically coupled to receive a
 4 second optical beam having a second wavelength, wherein the first input of the first MMI
 5 coupling device is optically coupled to output a multichannel optical beam including the first
 6 and second wavelengths combined.

1 5. The apparatus of claim 1 wherein the first and second optical couplers comprise
 2 first and second waveguides, respectively, disposed in the semiconductor substrate.

1 6. The apparatus of claim 5 wherein each of the first and second waveguides
 2 comprise silicon channels with oxide cladding disposed in the semiconductor substrate.

1 7. The apparatus of claim 1 wherein each of the first and second MMI coupling
 2 devices comprise silicon channels with oxide cladding disposed in the semiconductor
 3 substrate.

1 8. The apparatus of claim 7 wherein the insulative cladding of the first and second
 2 MMI coupling devices include a buried insulating layer of a silicon on insulator (SOI) wafer.

1 9. The apparatus of claim 1 wherein the semiconductor substrate comprises silicon.

1 10. The apparatus of claim 1 wherein the semiconductor substrate comprises a III-V
2 type semiconductor material.

Q1 1 11. The apparatus of claim 1 further comprising an optical switch disposed in the
2 semiconductor substrate having first and second inputs and first and second outputs, the first
3 and second inputs of the optical switch optically coupled to the first and second outputs,
4 respectively, of the second MMI coupling device.

1 12. The apparatus of claim 1 further comprising an optical switch disposed in the
2 semiconductor substrate having first and second inputs and first and second outputs, the first
3 and second outputs of the optical switch optically coupled to the first and second inputs,
4 respectively, of the first MMI coupling device.

1 13. An apparatus, comprising:
2 a first, second and third optical interleavers, each of the first, second and third
3 interleavers including:
4 first and second multi-mode interference (MMI) coupling devices disposed in a
5 semiconductor substrate, each of the first and second MMI coupling devices of each of the
6 first, second and third optical interleavers including first and second inputs and first and
7 second outputs;

8 a first optical coupler having a first optical path length, the first output of the first
 9 MMI coupling device optically coupled to the first input of the second MMI coupling device
 10 through the first optical coupler; and

11 a second optical coupler having a second optical path length, the second output of the
 12 first MMI coupling device optically coupled to the second input of the second MMI coupling
 13 device through the second optical coupler, wherein the first optical path length is different
 14 than the second optical path length,

15 wherein the first output of the second MMI coupling device of the first optical
 16 interleaver is optically coupled to the first input of the first MMI coupling device of the
 17 second optical interleaver,

18 wherein the second output of the second MMI coupling device of the first optical
 19 interleaver is optically coupled to the second input of the first MMI coupling device of the
 20 third optical interleaver.

1 14. The apparatus of claim 13 wherein the first input of the first MMI coupling
 2 device of the first optical interleaver is optically coupled to receive an optical beam having a
 3 plurality of channels, each one of the plurality of channels having a corresponding
 4 wavelength,

5 wherein the first output of the second MMI coupling device of the second interleaver
 6 is optically coupled to output a first one of the plurality of channels of the optical beam,

7 wherein the second output of the second MMI coupling device of the second
 8 interleaver is optically coupled to output a second one of the plurality of channels of the
 9 optical beam,

10 wherein the first output of the second MMI coupling device of the third interleaver is
 11 optically coupled to output a third one of the plurality of channels of the optical beam,
 12 wherein the second output of the second MMI coupling device of the third interleaver
 13 is optically coupled to output a fourth one of the plurality of channels of the optical beam.

a¹ 1 15. The apparatus of claim 13 wherein the first input of the first MMI coupling
 2 device of the first optical interleaver is optically coupled to receive an optical beam having a
 3 plurality of channels, each one of the plurality of channels having a corresponding
 4 wavelength,

5 wherein the first output of the second MMI coupling device of the second interleaver
 6 is optically coupled to output a first subset of the plurality of channels of the optical beam,

7 wherein the second output of the second MMI coupling device of the second
 8 interleaver is optically coupled to output a second subset of the plurality of channels of the
 9 optical beam,

10 wherein the first output of the second MMI coupling device of the third interleaver is
 11 optically coupled to output a third subset of the plurality of channels of the optical beam,

12 wherein the second output of the second MMI coupling device of the third interleaver
 13 is optically coupled to output a fourth subset of the plurality of channels of the optical beam.

1 16. The apparatus of claim 13 wherein the first output of the second MMI coupling
 2 device of the second interleaver is optically coupled to receive a first optical beam having a
 3 first wavelength,

4 wherein the second output of the second MMI coupling device of the second
 5 interleaver is optically coupled to receive a second optical beam having a second wavelength,

6 wherein the first output of the second MMI coupling device of the third interleaver is
 7 optically coupled to receive a third optical beam having a third wavelength,
 8 wherein the second output of the second MMI coupling device of the third interleaver
 9 is optically coupled to receive a fourth optical beam having a fourth wavelength,
 10 wherein the first input of the first MMI coupling device of the first optical interleaver
 11 is optically coupled to output a multichannel optical beam including the first, second, third
 12 and fourth wavelengths combined.

1 17. The apparatus of claim 13 further comprising:
 2 a first optical switch having first and second inputs and first and second outputs, the
 3 first and second outputs of the first optical switch optically coupled to the first and second
 4 inputs, respectively, of the first MMI coupling device of the first optical interleaver;
 5 a second optical switch having first and second inputs and first and second outputs,
 6 the first and second inputs of the second optical switch optically coupled to the first and
 7 second outputs, respectively, of the second MMI coupling device of the second optical
 8 interleaver; and
 9 a third optical switch having first and second inputs and first and second outputs, the
 10 first and second inputs of the third optical switch optically coupled to the first and second
 11 outputs, respectively, of the second MMI coupling device of the third optical interleaver.

1 18. A method, comprising:
 2 splitting an optical beam having a plurality of channels, each one of the plurality of
 3 channels having a corresponding wavelength, into first and second split optical beams;

4 directing the first split optical beam through a first optical coupler having a first
 5 optical path length into a first input of a first multi-mode interference (MMI) coupling
 6 device;

7 directing the second split optical beam through a second optical coupler having a
 8 second optical path length into a second input of the first MMI coupling device, wherein the
 9 second optical path length is different than the first optical path length;

10 outputting a first one of the plurality of channels of the optical beam from a first
 11 output of the first MMI coupling device; and

12 outputting a second one of the plurality of channels of the optical beam from a second
 13 output of the first MMI coupling device.

1 19. The method of claim 18 wherein outputting the first one of the plurality of
 2 channels of the optical beam comprises outputting a first subset of the plurality of channels of
 3 the optical beam from the first output of the first MMI coupling device.

1 20. The method of claim 18 wherein outputting the second one of the plurality of
 2 channels of the optical beam comprises outputting a second subset of the plurality of
 3 channels of the optical beam from the second output of the first MMI coupling device.

1 21. The method of claim 18 further comprising selectively optically coupling the first
 2 one of the plurality of channels to be output from a first or second output of an optical switch.

1 22. The method of claim 18 further comprising selectively optically coupling the
 2 second one of the plurality of channels to be output from a first output of an optical switch.

23. The method of claim 18 wherein splitting the optical beam into the first and second split optical beams comprises:

directing the optical beam into a first input of a second MMI coupling device;

outputting the first split optical beam from a first output of the second MMI coupling device; and

outputting the second split optical beam from a second output of the second MMI coupling device.

24. An apparatus, comprising:

an optical splitter having a first input and first and second outputs;

a first optical coupler having a first optical path length;

a second optical coupler having a second optical path length, the first optical path length different than the second optical path length; and

a first multi-mode interference (MMI) coupling device having first and second inputs and first and second outputs, the first input of the first MMI coupling device optically coupled to the first output of the optical splitter through the first optical coupler, the second input of the first MMI coupling device optically coupled to the second output of the optical splitter through the second optical coupler.

25. The apparatus of claim 24 wherein the input of the optical splitter is optically coupled to receive an optical beam having a plurality of channels, each one of the plurality of channels having a corresponding wavelength, wherein the first output of the first MMI coupling device is optically coupled to output a first one of the plurality of channels of the

5 optical beam, wherein the second output of the first MMI coupling device is optically
6 coupled to output a second one of the plurality of channels of the optical beam.

1 26. The apparatus of claim 24 wherein the input of the optical splitter is optically
2 coupled to receive an optical beam having a plurality of channels, each one of the plurality of
3 channels having a corresponding wavelength, wherein the first output of the first MMI
4 coupling device is optically coupled to output a first subset of the plurality of channels of the
5 optical beam, wherein the second output of the first MMI coupling device is optically
6 coupled to output a second subset of the plurality of channels of the optical beam.

1 27. The apparatus of claim 24 wherein the optical splitter comprises a second MMI
2 coupling device having first and second inputs and first and second outputs, the first and
3 second outputs of the second MMI coupling device optically coupled to the first and second
4 optical couplers, respectively.

1 28. The apparatus of claim 24 further comprising an optical switch having first and
2 second inputs and first and second outputs, the first and second inputs of the optical switch
3 optically coupled to the first and second outputs, respectively, of the first MMI coupling
4 device, the first and second outputs of the optical switch selectively optically coupled to the
5 first or second inputs of the optical switch.

1 29. The apparatus of claim 27 further comprising an optical switch having first and
2 second inputs and first and second outputs, the first and second outputs of the optical switch
3 optically coupled to the first and second inputs, respectively, of the second MMI coupling

- 4 device, the first and second outputs of the optical switch selectively optically coupled to the
- 5 first or second inputs of the optical switch.

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